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The association between the north Indian Ocean and summer monsoon rainfall over India

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सार — वर्ष 1961 से 81 तक की अवधि के समुद्री मौसम विज्ञान आंकड़ों का प्रयोग करते हुए, 0°-25° उ.,50°-100° पूर्व से घिरे हुए हिन्द महासागर के उत्तरी क्षेत्र में 5° ग्रिड-जाली पर प्रत्येक वर्ष के समुद्र तल दाब (एस एल पी) और समुद्र सतह तापमान (एस एस टी) के वितरण का पता लगाया गया है। यह पाया गया कि मई माह का समुद्र तल दाब और समुद्र सतह तापमान भारत में उत्तरवर्ती ग्रीष्मकालीन मानसून वर्षा की पूर्वानुमानित सूचना देता है। उत्तरवर्ती ग्रीष्मकालीन मानसून ॠतु के अखिल भारतीय वर्षा परिवर्तनों और अरब सागर तथा बंगाल की खाड़ी के 5°-10° उ. , 10 °-15° उ., 15-20° उ., 20° -25° उ., के अक्षांशीय कटिबंधों में मई माह के औसत समुद्र तल दाब के बीच महंत्वपूर्ण नकारात्मक सहसंबंध पाए गए हैं। मई माह के दौरान अरब सागर में 7.5° - 17.5° उ. के बीच औसत समुद्र सतह तापमान प्रवणता का उत्तरवर्ती मानसून की अखिल भारतीय वर्षा के साथ महत्वपूर्ण सकारात्मक सहसंबंध पाया गया है। इस अध्ययन से यह ज्ञात होता है कि हिन्द महासागर के उत्तर में मई माह के समुद्र तल दाब और समुद्र सतह तापमान की कुछ क्रियाएं भारत में उत्तरवर्ती ग्रीष्मकालीन मानसून वर्षा के लिए उपयोगी पूंर्वसूचक सिद्ध हो सकती हैं।

ABSTRACT. Utilizing the marine meteorological data of the period 1961-81, the sea level pressure (SLP) and sea surface temperature (SST) distributions have been obtained on a 5° grid-mesh over the north Indian Ocean area bounded by 0° - 25°N, 50°- 100°E for each individual year. It has been found that the SLP and SST fields for the month of May provide predictive indications of subsequent summer monsoon rainfall over India. Significant negative correlations have been found between the mean SLPs of May over the latitudinal belts 5°-10°, 10°- 15°, 15°-20° and 20°-25°N of Arabian Sea and Bay of Bengal and all India rainfall departures of succeeding summer monsoon season. The mean SST gradient over the Arabian Sea between 7.5°-17.5°N during May has been found to have significant positive correlation with all India rainfall of subsequent monsoon. The study suggests that certain functions of SLP and SST of May over the north Indian Ocean can prove to be useful predictors for subsequent summer monsoon rainfall over India.

Key words — Sea level pressure (SLP), Sea surface temperature (SST), Summer monsoon, Correlation Coefficient (CC), Predictor.

1. Introduction

The summer monsoon rainfall over Indian subcontinent possesses large interannual variability. There are indications that the variations in the activity of summer monsoon are related to the variations of the circulation, Sea Level Pressure (SLP), Sea Surface Temperature (SST) etc. over the Indian Ocean. Shukla and Misra (1977) have suggested the links between SST and wind speed over the central Arabian Sea, and the monsoon rainfall over India. Weare (1979) has studied the relationship between SSTs and the Indian monsoon. Singh (1993) and Singh and Joshi (1993) have shown that meteorological and oceanographical conditions, prevailing over the north Indian Ocean before the commencement of summer monsoon season, have significant influence on the subsequent monsoon rainfall over India. The objective of this paper is to document the interannual variabilities of SLP, SST and their gradients over the north Indian Ocean (north of Equator) and to study their relationships with the variability of summer monsoon rainfall over India.

2. The data and methodology

About one lakh marine meteorological observations for the month of May during the period 1961-81 recorded over the north Indian Ocean have been processed and analysed.

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TABLE 1

CCs between the mean SLPs of different latitudinal belts and all India rainfall departure for summer monsoon

S. No.	Predictor	CC with the rainfall departure
1.	Mean SLP over 0°-5°N	– 0.37
2.	Mean SLP over 5°-10°N	– 0.54**
3.	Mean SLP over 10°-15°N	– 0.52**
4.	Mean SLP over 15°-20°N	– 0.56*
5.	Mean SLP over 20°-25°N	– 0.58**

*Significant at 1 % level ** Significant at 5 % level

For the determination of SST fields the data has been supplemented by the real-time marine observations and the ships log data of Indian Voluntary Observing Fleet for the period 1982-91. This was done to enlarge the time- series of SST, which appeared necessary keeping in view the lesser number of SST observations as compared to those of SLP. Needless to mention, only selected ships report SST, whereas, SLP is reported by all ships, namely selected, supplementary and Auxiliary. Thus the SST variations have been studied for the period 1961-91 (for Arabian Sea only) whereas, the SLP variations have been studied for 1961-81 (for Arabian Sea and Bay of Bengal both).

The summer monsoon rainfall data published in Mausam have been utilized to obtain the all India area-weighted rainfall departures from normal for June to September.

The monthly means of SLP for May month have been worked out for each 5° square over the north Indian ocean area north of Equator between 50°- 100°E for each individual year of the period 1961-81. The means of SLP have also been computed for each of the latitudinal belts, 0-5°, 5°- 10°, 10°-15°, 15°-20° and 20°- 25°N covering the areas of Arabian Sea and Bay of Bengal both. The Coefficient of Correlation (CC) between the mean SLP of each of above latitudinal belts and all India percentage rainfall departure from normal for June to September has been computed. The CCs between the north-south pressure gradients over Arabian Sea and Bay of Bengal, and all India rainfall of summer monsoon season have also been computed.

The monthly means of SST for May have been obtained for each 5° square over the Arabian Sea area bounded by 5°-20°N between 50°-80°E. The CC between mean SST of each of the areas 5°-10°N and 50°-80°E, 10°- 15°N & 50°-80°E and 15°-20°N & 50°-80°E, and all India rainfall departure of summer monsoon season has been computed. In addition, the CC between the mean SST gradient over the Arabian Sea (7.5°-17.5°N) and seasonal rainfall over India has also been computed.

TABLE 2

CCs between the SLP gradients of May and the succeeding monsoon rainfall over India

S. No.	SLP parameter	CC with the rainfall departure
1.	Mean SLP gradient over the Arabian Sea between 22.5°-2.5°N	+ 0.19
2.	Mean SLP gradient over the Bay of Bengal between 17.5°-2.5°N	+ 0.23
3.	Mean SLP gradient between the Head Bay of Bengal and the southwest Arabian Sea area, 0.5° N, 50°-60° E	+0.38

3. Results and discussion

3.1. *Relationship between the SLP fields during May over Arabian Sea and Bay of Bengal, and the activity of subsequent summer monsoon over India*

The CCs between the mean SLPs of May over different latitudinal belts of the Arabian Sea and Bay of Bengal and all India percentage rainfall departures from normal for subsequent summer monsoon have been given in Table 1.

It is evident from Table 1 that there exists a negative correlation between the SLP of May over the north Indian Ocean (north of the Equator) and the subsequent Indian summer monsoon rainfall. Generally, the CC-values increase monotonically from the Equator to 25°N. Thus the SLPs of northern Arabian Sea and northern Bay of Bengal are significantly correlated to the Indian monsoon rainfall. The mean SLP of the Equatorial north Indian Ocean (0°-5°N) does not show any significant correlation with the monsoon rainfall. It appears that the mean SLP of May over the north Indian Ocean area between the latitudes 5°N and 25°N can prove to be a useful predictor for the subsequent monsoon rainfall over India. This predictor would be highly stable as it is consistently showing negative correlation over a vast oceanic area. Another significant feature is that there is a very little latitudinal variation in the CCs from 5°N to 25°N (the CCs range from –0.54 to –0.58 only). Due to this reason it is advisable to consider the mean SLP of entire oceanic area from 5°-25°N as predictor for the monsoon rainfall.

Due to the lower magnitude of CC for the SLP over 0°-5°N as compared to those over the northern parts of Arabian Sea and Bay of Bengal, the probable correlation between the north-south SLP gradients over the Arabian Sea and Bay of Bengal, and the monsoon rainfall was also looked into. But no significant correlation between the SLP gradients and the monsoon rainfall could be found. The computed CCs are given in Table 2.

The interesting aspect of the CC-values shown in Table 2 is that all CCs are positive. The CC between the SLP gradient from Head Bay to extreme southwest Arabian Sea and the monsoon rainfall which is + 0.38 deserves some attention. It is well known that the direction of pressure

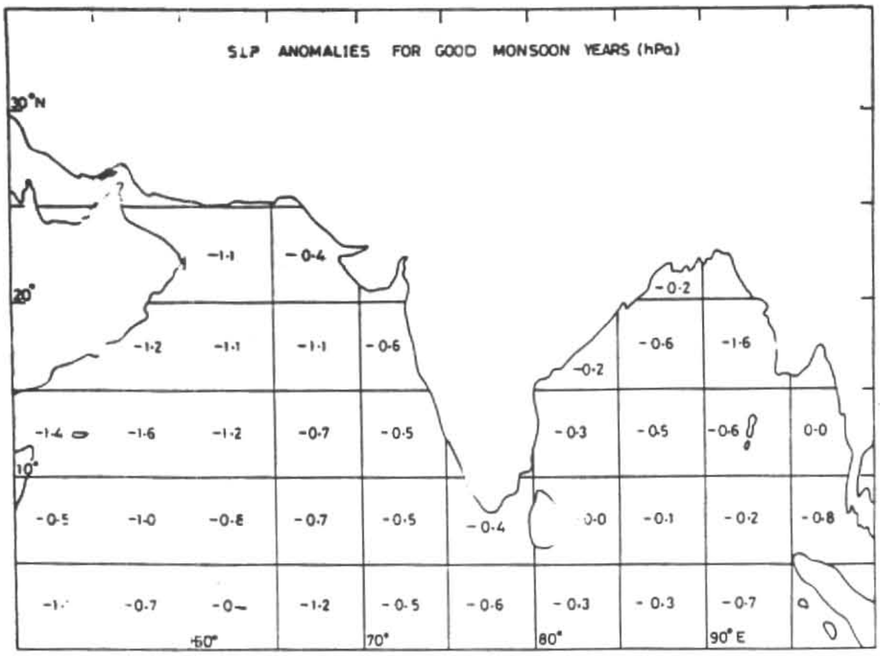

Fig.1. Composite SLP anomalies for the month of May of good summer monsoon years of 1961, 1970 and 1975

gradient force over the north Indian Ocean (north of Equator) during the month of May is from southwest to northwest. In other words highest SLPs are observed over the southwest Arabian Sea and the lowest SLPs are observed over the Head Bay of Bengal during May. Although the pressure gradient force between the Mascarene High area and the northern parts of Indian seas may be of paramount importance for the monsoon, the pressure gradients over the Indian seas themselves cannot be overlooked. Higher initial pressure gradient force over the Indian seas before the commencement of summer monsoon appears to be favourable for the monsoon. But the role of the pressure gradient over the Indian seas seems to be much less significant as compared to the mean pressure itself. This is, perhaps, the best interpretation that can be made of various computed CCs between SLP parameters and the monsoon rainfall.

The gridwise composite SLP anomalies during May of the good and bad summer monsoon years have been presented in Figs.1 and 2 respectively. The good summer monsoon year has been defined as the year during which all India summer monsoon rainfall exceeded 110% of the normal and the bad monsoon year as the one during which all India monsoon rainfall was less than 90% of the normal rainfall. Thus during 21 years period from 1961-1981, the years 1961, 1970 and 1975 were taken to be good monsoon years whereas the years 1965, 1966, 1968, 1972, 1974 and 1979 turned out to be bad monsoon years. The striking feature brought out by Figs.1 and 2 is that the entire oceanic area of the Arabian Sea and Bay of Bengal was dominated by negative SLP anomalies during good monsoon years whereas during May of bad monsoon years positive anomalies prevailed. Another aspect revealed by the spatial distributions of SLP anomalies is that the contrast of anomalies during good and bad monsoon years appears to be more pronounced over the Arabian Sea as compared to that over the Bay of Bengal. Further, over the Arabian Sea itself the anomaly contrast between good and bad monsoon years is more over the western Arabian Sea.

These features are clearly brought out by Figs.3 and 4 which depict longitudinal and latitudinal variations of composite SLP anomalies during good and bad monsoon years. Thus the mean SLP of May over the Arabian Sea, particularly over the area; 5°-20°N between 50°-65°E appears to possess promise for a potential predictor for the subsequent summer monsoon rainfall over India.

3.2. *Relationship between the SST distribution during May over the Arabian Sea and the activity of subsequent summer monsoon over India*

The CCs between mean SSTs of May over different latitudinal belts of Arabian Sea and all India percentage rainfall departures for subsequent summer monsoon season have been given in Table 3.

Although the CCs shown in Table 1 are not very high, the interesting aspect is that there exists a negative correlation between SST of 5°-10°N and the monsoon rainfall, whereas the CC is positive from SST of 15°-20°N and the rainfall. This clearly shows that SST itself does not appear to be a potential predictor for the monsoon rainfall, whereas

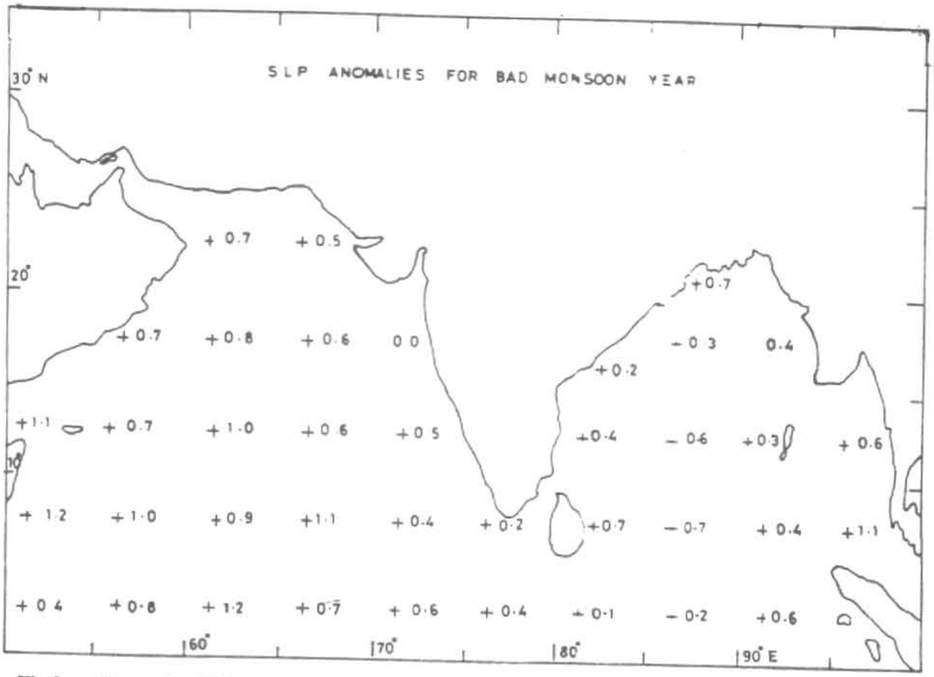

Fig.2. Composite SLP anomalies for the month of May of bad summer monsoon years of 1965, 1966, 1968, 1972, 1974 and 1979

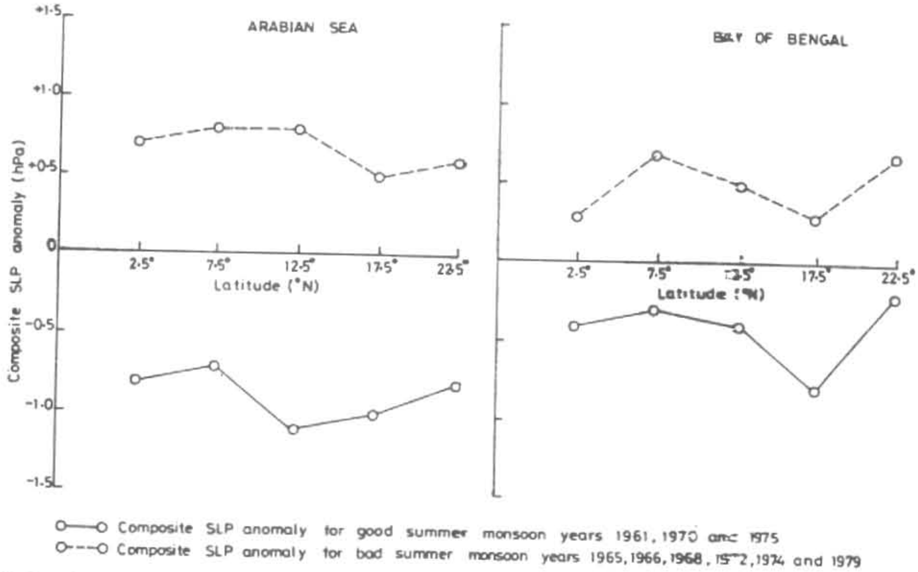

Fig.3. Latitudinal distribution of composite SLP anomalies during May over the north Indian Ocean for good and bad summer monsoon years

SST gradient from 7.5° to 17.5°N is a potential predictor. Necessitated with this observation, the CC between SST gradient over the Arabian Sea during May and the ensuing summer monsoon rainfall over India was computed which turned out to be highly significant; the value being +0.61 (significant at 1% level).

The gridwise composite SST anomalies over the Arabian Sea during May of good and bad monsoon years have been given in Figs.5 & 6. As pointed out in Section 2 the gridwise SST normals have been obtained using the data of 31 years period from 1961-91. During this period the good summer monsoon years were 1961, 1970, 1975, 1983 and 1988, whereas bad monsoon years were 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986 and 1987. The interesting features brought out by Figs.5 and 6 are the following:

(*i*) It is evident from Fig.5 that south Arabian Sea area between 5°-10°N was consistently dominated by negative SST anomalies, whereas north and adjoining central Arabian Sea

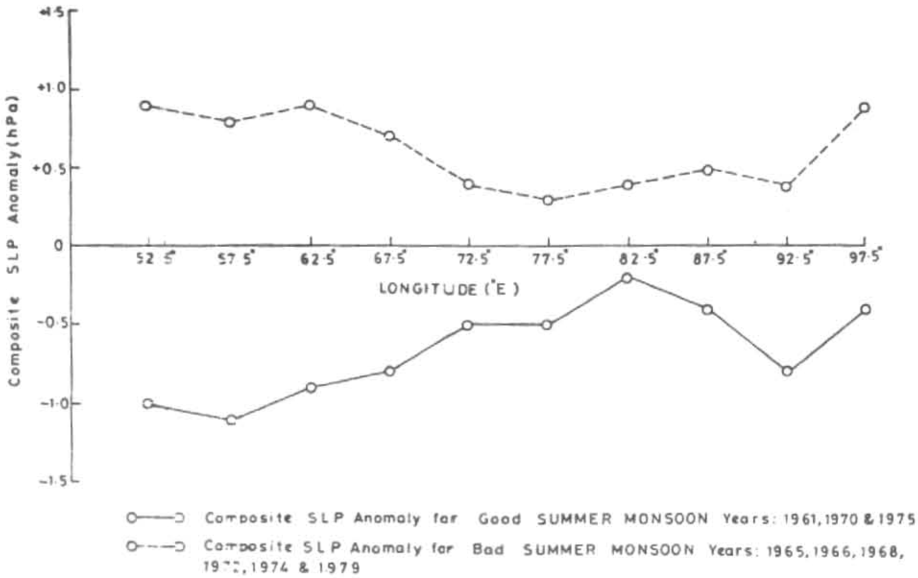

Fig.4. Longitudinal variation of composite SLP anomalies during May over the Arabian Sea and Bay of Bengal for good and bad monsoon years

TABLE 3

CCs between mean SSTs of different latitudinal belts and all India rainfall departure for summer monsoon

S. No.	Predictor	CC with the rainfall departure
1.	Mean SST over Arabian Sea between 5°- 10°N	−0.21
2.	Mean SST over Arabian Sea between 10°- 15°N	+0.17
3.	Mean SST over Arabian Sea between 15°- 20°N	+0.30

area between 15°- 20°N was covered by positive SST anomalies during May of good monsoon years. The latitudinal belt 10°-15°N appears to be the transitional belt where the anomalies ranged from -0.3°C to + 0.4°C from west to east. The highest negative anomaly (-0.6°C) was observed over extreme southwest Arabian Sea area between 5°-10°N, 50°- 55°E; whereas, highest positive anomaly (+0.4°C) was observed over the areas 15°-20°N, 60°- 65°E, 10°-15°N and 70°-75°E. Thus south Arabian Sea between 5°-10°N tends to be cooler than normal and the north and adjoining central Arabian Sea between 15°-20°N tends to be warmer than normal during May month of good monsoon years.

(*ii*) Fig.6 shows that positive SST anomalies prevailed over the south Arabian Sea area between 5°- 10°N, whereas the anomalies were negative over the latitudinal belt 15°-20°N during May of bad monsoon years. Thus south Arabian Sea between 5°-10°N showed cooler tendencies, whereas north and adjoining central Arabian Sea between

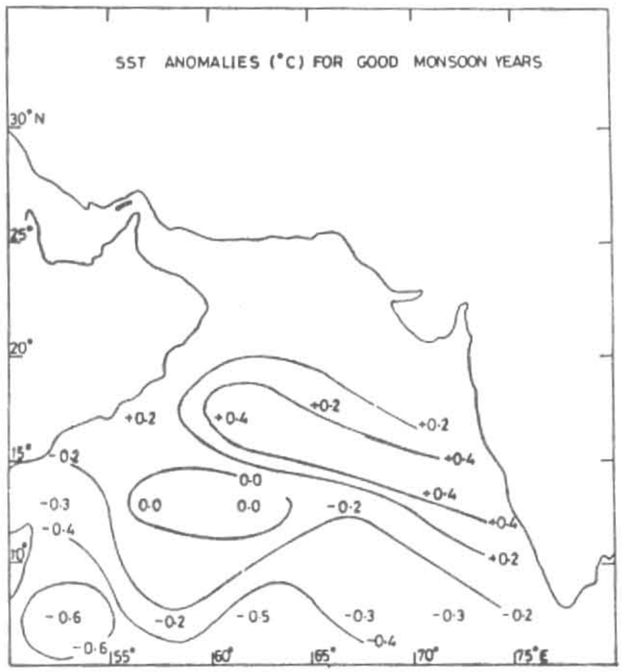

Fig.5. Composite SST anomalies for the month of May of good summer monsoon years of 1961, 1970, 1975, 1983 and 1988

15°-20°N showed warmer tendencies before the commencement of bad summer monsoons.

This type of change in the SST field over the Arabian Sea in May appears to be interesting as well as significant. The pronounced fluctuations in the SST are exhibited by the areas; 15°-20°N between 60°-65°E, 5°- 10°N between 50°-55°E and 10°-15°N between 70°-75°E. The differences in the SSTs during May of good and bad monsoon years over these areas are 1.1°C, 1.0°C and 0.8°C, respectively which

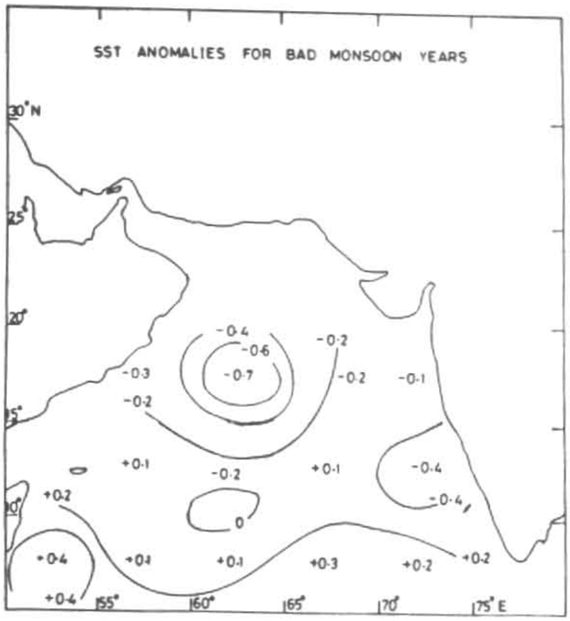

Fig.6. Composite SST anomalies for the month of May of bad monsoon years of 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986 and 1987

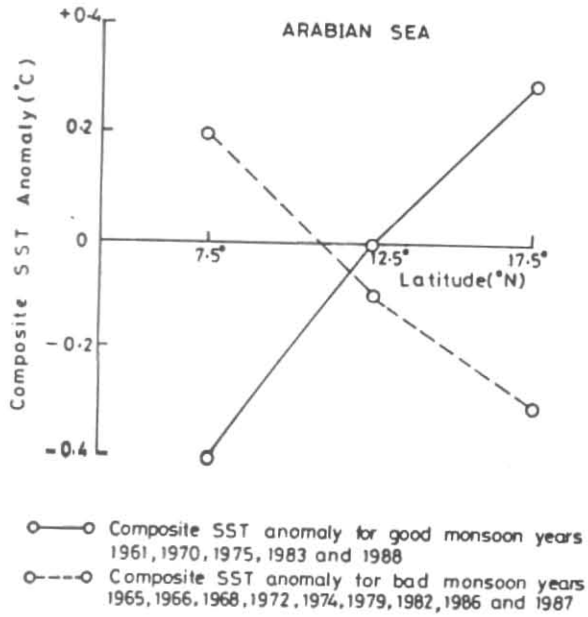

Fig.7. Latitudinal variation of composite SST anomalies during May over the Arabian Sea for good and bad summer monsoon years

appear to be substantial. Thus it is not surprising that the mean SST gradient between 7.5°N to 17.5°N over the Arabian Sea during May showed significant correlation with the monsoon rainfall.

The latitudinal variation of composite SST anomalies during May of good and bad monsoon years has been shown in Fig.7 which shows that the anomaly contrasts for good and bad monsoon years are pronounced at the mean latitudes 7.5°N and 17.5°N. There is a very little difference in the mean composite anomalies at the mean latitude 12.5°N.

4. Conclusions

In the context of Indian summer monsoon a question is often asked; "How important is the initial state of Indian Seas, particularly of the Arabian Sea for the subsequent monsoon?" The present study has partially answered this question. The study has clearly shown that the distributions of the atmospheric pressure and the sea surface temperature over the north Indian Ocean during the later period of pre-monsoon season do have strong associations with the subsequent monsoon. From amongst different pressure and SST parameters of north Indian Ocean, two parameters; namely, the mean atmospheric pressure over the Arabian Sea (north of 5°N) during May, and the mean SST gradient over the Arabian Sea between 7.5°N and 17.5°N during May hold promise to become potential predictors for the Indian summer monsoon rainfall.

However, it may be admitted that only pressure and SST do not fully define the initial state of the sea and its overlying atmosphere. Different energy exchange processes taking place at the sea-air interface are also important. Thus there are a number of oceanic parameters, which are functions of pressure, SST wind, moisture and air temperature that define the state of the sea and the overlying atmosphere in a more complete sense. Further analysis suggests that the oceanic predictors from the Indian ocean would be very useful in the prediction of monsoon rainfall/onset due to their physical linkages with the monsoon.

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